Adoption paths for barcode and RFID technologies in the medication process: full implementation, hybridization or migration

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Abstract—Medication errors are considered as the most frequent type of adverse events occurring in hospitals. Technology, such as barcode and RFID, can lower the frequency of adverse medication events by improving quality and communication, by tracking patients and medication doses, by preventing errors, by facilitating a more rapid response after the incidence of an error, and by documenting and analyzing adverse events. This paper explores four different adoption paths for improving the medication process of an emergency department, namely full barcode implementation, full RFID implementation, hybridization, or migration. More specifically, it attempts to assess if each of these adoption paths is better suited to support the activities related to the stages of the medication process.

Keywords—Adverse medication events, RFID, barcode, technology adoption.

I. INTRODUCTION

Reducing adverse medication events and improving patient safety are recognized as a high priority for the management of health care systems [1]. In fact, the Institute of Medicine (IOM) has reported that between 80,000 and 116,000 hospitalized patients die in the U.S. because of an adverse event [2]. The problem of medication errors is worrisome since one to two million of patients in U.S. are affected every year by medication-related problems [3]. Indeed, medication errors are considered as the most frequent type of adverse events noted in the IOM report [4] and, on average, a North-American patient experiences at least one medication error per day [5]. Beside their negative impact on human health, medication errors entail rather significant costs. Indeed, adverse drug events in hospitalized patients are responsible for more expensive and longer hospitalizations [6]. According to Bates [7], medication errors increase the length of stay by as much as 4.6 days and a longer stay costs $4,685 per event. In North America, medication errors represent an annual cost of $2.8 million for a typical 700-bed hospital [8]. Fortunately, research shows that about 50% of adverse medication events are preventable [7].

The introduction of information technology, such as Computerized Physician Order Entry (CPOE), e-prescribing, clinical decision support or smart pumps, can promote safe medication practice. Barcode and RFID technologies are the two main technological advances that hospitals are relying on to decrease the occurrence of adverse medication events. These technologies can enhance patient safety at any stage of the medication process. The use of barcode for the administration stage tends to increase exponentially in healthcare organizations in the United States and Europe. According to a current review of relevant literature, adoption of barcode is mandatory to ensure the five rights of the medication administration process: right drug, right route, right patient, right dose, and right time [9]. In contrast, RFID, considered as a potential successor to barcode, offers more advantages [10] but its adoption rate remains much lower than the one experienced by barcodes. The extent to which the adoption of RFID is significantly affected by the omnipresence of the “old” barcode technology remains unknown.

This paper explores the potential adoption paths for barcode and RFID technologies in the medication process, namely full barcode implementation, hybridization, migration and full RFID implementation. More specifically, we will assess if each of these adoption paths is better suited to support the activities related to the stages of the medication process. This paper is structured as follows. The next section presents the different stages of medication process, provides a brief overview of the barcode and RFID technologies and examines the different adoption paths. The third section presents the methodology while some preliminary results are discussed in the fourth section. The fifth and last section offers some concluding remarks.

II. BACKGROUND

A. The medication process

Health governmental institutions, healthcare facilities and, researchers are actively involved in the improvement of patient safety [11]. Because patient safety in hospitals cannot be taken for granted, adverse medication events have become an important, frequently studied and discussed phenomenon [11]. Several studies have showed that errors are not produced by the negligence or incompetence of healthcare practitioners, but are rather the result of the organization of medication
process, the way the medication service is delivered and the availability of resources [12]. The medication process is complex and error prone mainly due to the large number of processes and the wide array of healthcare facilities, professionals and personnel involved. Any process within medication system, combined with the context of limited resources, may represent a potential source of adverse medication events that can damage patients’ health.

The process for ensuring the medication service in a hospital facility is lengthy and contains numerous steps [13]. The medication process covers five main stages: ordering, transcribing, dispensing, administering and monitoring (see figure 3). Although many factors can contribute to medication errors, starting from the initial step of writing a prescription to the last step when monitoring the patient [14], previous research on medication errors tends to focus on two main stages, namely ordering and administration that are considered by Trossman [15] as less secure. In fact, adverse medication errors occur most frequently in ordering (34.7%) and administration (36.9%) stages [15] and 90% of these errors could be prevented [7]. Some researchers [13] reported that inappropriate identification of the patient and incorrect doses are the two main causes of errors during these two stages.

Despite all the efforts made to improve medication safety, such as education, errors reporting, performance improvement initiatives and process redesign, adverse medication events continue to occur in all stages of the medication process. The reliance of various technologies like barcodes and smart pumps is considered as a new option to reduce medication errors [8], [13].

B. New technologies adoption for the medication process

Technology can lower the frequency of adverse medication events by improving quality and communication, by tracking patients and medication doses, by preventing errors, by facilitating a more rapid response after the incidence of an error, and by documenting and analyzing adverse events [8].

In the last years, several healthcare institutions, including IOM and WHO, have started to focus on technological solutions for safe medication strategies [16]. According to the literature, the most common type of technology implemented in several healthcare facilities in the North America, Europe and Asia are Electronic Medical Record (EMR), Computerized Physician Order Entry (CPOE), Pharmacy Information System (PIS), smart infusion pumps and barcode technology. Besides their capacity to allow safe zero-error medication process and improve effectiveness, these technologies can decrease the costs of healthcare services since repetitive routine human activities could be automated [8]. Many of those technologies are being developed and directly integrated into the medication process while others are waiting for full implementation.

Among the most prevalent adopted technologies, barcode is used to verify patient identification, and to prepare, distribute and administer medication doses [17]. Since the Food and Drugs Administration (FDA) had suggested the use of barcode for tracking medicines in 2003, the healthcare facilities turned increasingly to barcode for ensuring the five’s rights of medication [18]. The success of the barcode technology has been highly documented. For instance, the Veterans Affairs Medical Centre stated that the application of barcodes on patient beds and medication doses could reduce 86% of adverse events [18], allowing 5.7 millions of savings [19]. More recently, FDA reports that barcode adoption for the medication process can prevent 50% of adverse events [20]. In recent years, barcode adoption has become mandatory to ensure the quality of healthcare services. For instance, the American Recovery and Reinvestment Act of 2009 provides financial incentives to hospitals for the use of barcodes for the medication process [21].

RFID technology is “considered as the potential successor of barcode technology” [23, p.1]. RFID and barcode are conceptually similar and belong both to the same technology family, namely Auto-Identification and Data Capture (AIDC). The AIDC solutions share the same capacity to track objects, humans and animals. In the medication process, both the barcode technology and the RFID technology accomplish the same requirement, namely the identification of medicines and patients and they can both prevent adverse medication events. However, these two technologies are different because of two main reasons: i) barcode is read-only whereas RFID is read and write, and ii) barcode requires a line of sight for lecture whereas RFID is contactless, data being transmitted by radio frequency [19, 24]. Because RFID allows automatic lectures, manual labor can be replaced by semi or totally automated processes [25, 26] and as a consequence, potential human errors could be prevented. Several technological organizations were quite optimistic about RFID potential and have envisioned that RFID would rapidly be implemented in healthcare applications. For instance, ID TechEx estimated that the market of RFID solutions for healthcare in North America would grow from 90 million in 2006 to 2.1 billion in 2016 [27].

Even if RFID is often considered as more promising than barcode, RFID is not widely adopted in the healthcare and cannot totally replace the “old technology” barcode. It seems that “the prevalence of barcode, are likely to affect the adoption and diffusion of RFID technology” [23, p.1]. Nevertheless, some scholars predict that RFID, once more mature and less costly, could gradually replace the current barcode systems in healthcare [19] and healthcare facilities are currently facing several adoption paths as it will be discussed in the next section.

C. Adoption paths for barcode and RFID

In order to improve the safety of the medication process, the following adoption paths may be considered: full implementation of barcode technology, full implementation of RFID technology, integration or hybridization of both technologies, or migration from barcode to RFID. Between the full barcode implementation aimed at the identification of assets, medicines and medical staff and the full RFID implementation meant to improve safety, stock control and real-time traceability, co-existence between barcode and RFID is increasingly being accepted by industry and academic: [19], [23], [28]. When an old and a new technology can fulfill similar tasks, the transition from the older one to the new one can be reflected by the co-existence of both technologies. The older technology can be a prerequisite for full implementation of a new technology and even accelerate its adoption [23]. The
old technology can be used for critical processes and as a backup solution while new technology performance is assessed. Nevertheless, “the longer the transition phase continues, the more it will become ingrained into application as a de-facto standard” [28, p.3]. Co-existence means that healthcare facilities can either migrate from barcode to RFID or choose a hybrid solution that capitalizes on both barcode and RFID (see Figure 1). The main focus of this paper is to analyse the different adoption paths and their potential for each stage of the medication process.

![Adoption paths diagram](image)

Fig 1. Adoption paths (adapted from [29])

III. METHODOLOGY

The field research consists of a detailed case study that was conducted over a period of one year. The research objectives are twofold, namely to evaluate the main issues of the medication process and to assess the prospective benefits of each adoption path for each stage of the medication process. The healthcare facility retained for the case study is a 600-bed hospital located in the Montreal metropolitan area. Participants to the study are health professionals, hospital managers, IT specialists, pharmacy equipment manufacturers and consultants.

The case study includes four distinctive phases. The first phase consists of an in-depth analysis of medication process in the emergency department. In the second phase, information flow charts and business processes were mapped while critical processes have also been identified. The third phase corresponds to the evaluation of potential benefits and to the assessment of impacts generated by barcode or RFID technology adoption at each step of the medication process. Technological merits of each adoption path were also evaluated by hospital staff. During the forth and last phase, each adoption paths was discussed in focus groups with healthcare practitioners and technology providers.

We rely on multiple sources of empirical evidence, including multiple on-site observations, semi-structured interviews, and, internal and external documentation. This paper presents the preliminary results obtained during the three first phases of the case study.

IV. PRELIMINARY RESULTS

A. The research site: the Emergency Department

The Emergency Department has been selected as the research site because of the high frequency of adverse medication events. This 45-bed department is characterized by a high volume of patients with critical and sometimes life-threatening conditions: it attends to approximately 33,000 patients annually requiring a wide variety of immediate and unplanned healthcare services. For patients with less critical conditions, the hospital emergency room waiting time to physician varies widely and can be exceptionally long during certain periods. On average, slightly less than 65 staff members are working in three different shifts. The work environment in the emergency department is dynamic, complex, fast-paced, extremely demanding and therefore prone to medication errors.

The emergency department is divided into three main services, namely, ambulatory, acute care and reanimation, and has its own pharmacy (secondary pharmacy) with the most frequently used medicines. The central hospital pharmacy is responsible to give medication services (on average, more than 600 doses per day) to the emergency department.

The hospital pharmacy has recently adopted new automated distributors and automated unit-dose equipment: McKesson Acudose-Rx and McKesson PACMED. Because these equipments require the identification of medicines and doses using barcode technology, hospital pharmacy is building a barcode infrastructure to control its medicines and doses. Each medication dose is identified by a label containing patient name, medication name, quantity dose, administration instructions and a barcode (see figure 2). In the short term, this hospital will invest in a barcode medication administration BCMA infrastructure in order to ensure the medication process by identifying patient and doses at the administration point.

![Medication label](image)

Fig 2. Medication label

B. The medication process in the emergency department

In order to better understand the potential adoption paths for barcode and RFID, the medication process has been thoroughly analyzed and the underlying processes were mapped using a drilled down approach from the most general to the most detailed processes (Figure 3). As displayed in
Figure 3, the medication process entails six broad processes or stages namely ordering, transcribing, preparing, distributing, administering and monitoring that are subdivided into twenty sub-processes (P1 to P20). The sub-processes are in turn subdivided into activities (P1.1, etc.). The medication process involves several healthcare professionals, specialists and technicians.

The first two stages, ordering and transcribing, refers to elements such as selecting the correct medicine and processing the medication order. The physicians write an order by identifying a patient using his or hers healthcare file and bed number (see figure 3, sub-processes P1, P2 and P3). Before its transmission by pneumatic service, nurses must validate that medication order cannot be supplied by the emergency

![Image of the medication process]

**ORDERING PROCESS**
P1. Pick information patient  
P1.1. Pick patient profile file  
P1.2. Print patient information tag  
P2. Defining medication patient treatment  
P2.1. Identify patient by asking his name or checking the bed number  
P2.2. Evaluate patient condition  
P2.3. Define medication treatment  
P3. Writing medication order  
P3.1. Place patient information tag on a new medication order  
P3.2. Write medication order  
P3.3. Validate patient medication tag and medication order  
P3.4. Place medication order in the medication order carpet for transmission to the pharmacy

**TRANSCRIBING PROCESS**
P4. Transmit medication order to the pharmacy  
P4.1. Pick medication order from ED medication order carpet  
P4.2. Verify if medication order can be supplied at ED automated distributor  
P4.3. Transmit medication order by pneumatic system  
P4.4. Contact pharmacy service for urgent medication order  
P5. Receive medication order  
P5.1. Verify regularly the reception of medication orders by pneumatic system  
P5.2. Pick prescription order  
P5.3. Write date and hour of reception on medication order  
P5.4. Classify medication order by priority, hour and date  
P6. Transcribe medication order  
P6.1. Transcribing medication order in the PIS  
P6.2. Validate not missing information in the medication order  
P6.3. Contact ED in case of missing information  
P6.4. Transmit medication order to pharmacist for validation  
P7. Validate medication order  
P7.1. Pick medication order in function of its priority  
P7.2. Verify medication order in the PIS and in paper  
P7.3. Analyze medication order in order to find any pharma-therapy incidence  
P7.4. Contact ED physician in case of pharma-therapy incidence  
P7.5. Update medication order in the PIS and in paper in case of correction  
P7.6. Confirm the validation of medication order in the PIS  
P7.7. Print medication dose tags for preparation and distribution

**PREPARING PROCESS**
P8. Prepare medication dose bag  
P8.1. Pick tags printed after pharmaceutical validation  
P8.2. Place medication dose tags on medication bag  
P9. Prepare medication dose  
P9.1. Read medication dose tag information  
P9.2. Validate medication dose tag information  
P9.3. Select medicine in function of medication dose tag  
P9.4. Prepare medication dose  
P10. Validate medication dose  
P10.1. Verify correspondence between medication dose and medication tag information (content and packaging)  
P10.2. Confirm medication preparation in the PIS  
P10.3. Update medicine stock level control  
P10.4. Re-verify correspondence between medication dose and medication tag information (double verification)  
P10.5. Place medication dose bag in ED distribution cart  
P10.6. Print order for distribution

**DISTRIBUTING PROCESS**
P11. Prepare for distribution  
P11.1. Pick distribution order from ED distribution carpet  
P11.2. Validate the distribution order  
P11.3. Classify medication dose bag in function of defined distribution type  
P12. Distribution by pneumatic system  
P12.1. Transmit by pneumatic service the medication dose bags  
P12.2. Confirm distribution in the PIS  
P13. Distribution by assistant (scheduled distribution)  
P13.1. Arrive to the pharmacy service  
P13.2. Leave returned medication doses  
P13.3. Validate the distribution order  
P13.4. Place medication dose caskets in the distribution cart  
P13.5. Confirm distribution in the PIS  
P13.6. Distribute medication dose casket to the ED

**MONITORING PROCESS**
P14. Receive medication doses  
P14.1. Pick medication dose bags from pneumatic service  
P14.2. Place medication dose bags in the ED nurses desk  
P15. Validate medication dose reception  
P15.1. Verify distribution order  
P15.2. Verify medication tag information and distribution order  
P15.3. Place dose bag in returned casket in case of wrong distribution  
P15.4. Contact pharmacy service in case of missing medication dose  
P15.5. Confirm reception of medication dose in the PIS

**ADMINISTERING PROCESS**
P16. Validate medication dose  
P16.1. Pick medication dose bag  
P16.2. Identify information of patient in the dose tag  
P16.3. Pick patient profile file  
P16.4. Verify the validity of medication dose with the medication order of patient  
P16.5. Contact pharmacy service in case of error or missing information  
P16.6. Return medication doses with errors or missing information

**MONITORING PROCESS**
P19. Supervise patient  
P20. Communicate with physician and/or pharmacy service

Fig 3. The medication process
Without exception, the patient identification indeed, implemented for the ordering and administrating phases (from Matrix, Aztec). In particular, pharmacy equipment is thus compatible with barcode technology. Finally, barcode technology for identification and control of doses, prescriptions, patients and staff; the full RFID implementation offers additional advantages such as real time and automated tracking and monitoring of objects (here medication doses) and people (in this case, patients, medical professionals, technicians).

Full barcode implementation: Barcode has become the predominant solution to ensure identification in all the steps of the medication process (from P1 to P20). Empirical evidence points to different reasons. First, it is a mature technology with a low cost that has been widely adopted and adopted in several industries. Second, external actors such as the pharmaceutical sector, manufacturers of pharmacy automated equipment and healthcare institutions support the adoption of barcode technology. In particular, pharmacy equipment is thus compatible with barcode technology. Finally, barcode drawbacks, such as limited data capacity and lecture problems have been improved with two-dimensional barcodes (Data Matrix, Aztec).

Full RFID implementation: RFID can be totally implemented for the ordering and administrating phases (from P1 to P3 and from P16 to P20) since it allows anytime and without exception, the patient identification. Indeed, caregivers may have some difficulties to identify the patient when he is sleeping, unconscious or unable or unwilling to collaborate. If patient has a RFID wristband, healthcare professionals can easily read by radio wave the patient identification. Because hospitals tend to tag high value and high cost assets, a full RFID implementation for medication orders and doses would not yield an appropriate ROI. In particular, a full RFID implementation offers less potential for the preparation and distribution stages (from P8 to P15). Nevertheless, the full RFID implementation for identifying medicines and doses could bring other benefits outside the medication process. Pharmacy logistics activities such as reception, storing or distribution to central or secondary pharmacy could be improved by the RFID capacity to track and trace objects in real time without human intervention.

The co-existence between barcode and RFID technologies implies either the migration from barcode to RFID or a hybrid strategy relying on both technologies. The migration for barcode to RFID refers to the progressive implementation of RFID into a medication process. Barcode basically serves as a support mechanism for ensuring the operability of medication process during RFID implementation, while technological problems with the new technology are solved or while organization adapts itself to the new RFID system. When RFID systems reach total implementation and organization acceptance, barcode technology could be progressively removed from the medication process. The migration adoption path seems particularly fitted for the ordering, administering and monitoring processes (from P1 to P3 and from P16 to P20). For the preparation and the distribution stages (from P8 to P15), the migration adoption path could take a longer period due to high RFID costs. The hybridization capitalizes on the relative advantages of both technologies. Hybridization could be illustrated by two different ways: i) medication orders and medication doses are identified with a label holding both technologies and patients and healthcare givers are identified with a card or wristband containing both a barcode label and a RFID tag; ii) barcode is used to identify medication orders or doses while RFID identifies patients and healthcare staff. Hybridization could occur for all the steps of the medication process. For barcode and RFID lecture, there are readers which are able to recognize both technologies. At the preparation and the distribution stages (from P8 to P15), the hybridization path could be preferable to ensure the performance of automated equipment. Solutions such as Fulfill Rx, IntelliShelf-Rx of McKesson rely on RFID for the identification of each medicine container and on barcode for identification of doses. If the hybridization solution is adopted for the preparation stages, other automated equipment such as automated distributors or robots could operate with both technologies.

V. Conclusion

Barcode adoption has become a key primary technological strategy for improving healthcare service quality in general and point-of-care patient safety in particular but will RFID eventually replace the widely adopted barcode technology for decreasing adverse medication events? This paper explores four different adoption paths for improving the medication process of an emergency department, namely full barcode...
implementation, full RFID implementation, hybridization, or migration. It seems more likely that hospitals will opt for the coexistence of both technologies, either through hybridization or migration adoption strategies for several reasons. First, the current processes and the existing equipment such as automated medication preparing equipment, dose distributors and readers are totally compatible with either barcode or RFID. Second, the coexistence of the two technologies is aligned with the previous investments and efforts towards CPOE based on barcode and towards WIFI which is necessary RFID. Third, the coexistence path offers a broader potential, apart from the medication process, for ensuring the quality of pharmacy logistics activities and the compatibility with industry regulations.

Internal and external factors may modify the direction of the adoption paths. For instance, hospitals are inclined to postpone RFID applications when the ROI is uncertain or when the clinical utility is not fully demonstrated. Influences outside the healthcare sector could also have an impact on the selection of the adoption path. If the pharmaceutical industry, for instance, selects one of these technologies to identify medicines throughout the supply chain, the hospital pharmacy would tend to use the same technology for its own internal logistics activities and for the medication process. Even if coexistence between RFID and barcode by hybridization or migration seems to be the more optimal solution for the medication process, it remains necessary to assess the impact of this coexistence on the adoption and diffusion of RFID technology in the healthcare sector. Will the coexistence adoption model slow down the diffusion of RFID technology or will it accelerate it?

REFERENCES